Research Proposal

Performance Evaluation
Of Tack Coat Materials

presented to:

Wisconsin Highway Research Program

submitted by:

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Problem Statement

Tack coats are commonly used to prevent localized pavement shoving and sliding which may lead to slippage cracking and reduced pavement integrity. Tack coats are intended to bond constructed pavement layers together and ensure that the layers act monolithically when subjected to traffic loads. Insufficient or improper application of tack coat can result in a weak bond between hot mix asphalt (HMA) pavement layers or between HMA nd PCC pavement layers, causing the layers to act independently. The type of tack coat used, type and condition of the adhering surfaces, rate of tack coat application, application temperature, and curing conditions are all factors that directly affect the development of the interlayer bond. The intent of this laboratory-oriented study is to investigate tack coat performance using materials and methods common in the Wisconsin paving industry.

Recently completed WHRP study 0092-02-13 (Mehta and Siraj, 2007) investigated interlayer slippage in several Wisconsin pavements. The results of this study indicated that the probability of slippage could be correlated to the stiffness ratio between HMA pavement layers, and that a higher stiffness ratio indicated lower risk of slippage between pavement layers. It was reported that to achieve a higher stiffness ratio and thus reduce the probability of slippage, the thickness of the surface layer could be increased. The recommendations from this study, which were based primarily on the results of backcalculated pavement layer properties, did not provide any practical guidance for the proper usage of tack coats. To expand on these results, this study will investigate a means to reduce the risk of slippage by the proper utilization of tack coat materials.

Research Objectives

The specific objectives of this research study are:

- To evaluate the adhesion characteristics of tack coats approved or proposed for use within Wisconsin.
- To develop qualitative relationships between laboratory test results and expected field performance.
- To recommend the cost-effective combination(s) of tack coat materials and construction procedures which result in satisfactory performance.

Background and Significance of Work

It is widely recognized that the bond between constructed HMA layers play a critical role in the performance of the HMA pavement. When a poor bond between layers exists, slippage cracking often occurs where traffic accelerates, decelerates or turns. Poor compaction, top-down cracking and surface delaminations may also be attributed to inadequate interlayer bonding (West, 2006). A variety of asphaltic materials have been used to provide a strong mechanical bond between HMA layers. Asphalt emulsions are the most common choice for tack coat materials and but paving grade asphalts have also been used successfully. The common challenge is to determine the appropriate combination of tack coat material, application rate and application/pavement conditions.

A number of research studies have been completed with the aim of establishing appropriate test methods for evaluating the bond strength between pavement layers associated with tack coat applications. West, et al. (2005) focused on the development of a test method for characterizing the bond strength between fine and coarse graded HMA layers which included the evaluation of testing temperature, normal pressure, tack coat type, application rate and mixture type. In this study, CRS-2, CSS-1 and PG 64-22 tack coat materials were investigated using residual application rates of 0.02, 0.05 and 0.08 gal/yd^2. Bond strength tests were conducted on laboratory prepared specimens using a direct shear type test with a loading rate of 2 in/min and test temperatures of 50, 77 and 140 °F. The study concluded that the PG 64-22 binder provided higher bond strengths than the emulsions, that higher bond strengths were generally evident at the lower application rate, and that bond strengths were significantly reduces as test temperature increased. The study also recommended a minimum bond strength of 100 psi to ensure good performance.

Tashman, et al. (2006) investigated the bond strength of constructed pavement sections based on a factorial assessment of surface treatment, curing time, residual application rate and pavement location. Surface treatments included milled and non-milled, each with broom cleaning prior to tack coat application. Target residual application rates of 0, 0.018, 0.048 and 0.072 gal/yd^2 were used for the CSS-1tack coat material. A new 2-inch HMA overlay (1/2 inch NMAS) was applied on half of the test sections after the tack coat had enough time to cure and set (approx 2.5 hours) and on the other half with 3 minutes after tack coat application. UTEP Pull-Off tests were conducted on the cured sections before paving. Six-inch pavement cores were extracted on the day after paving and tested using the Torque Bond Test and the FDOT Shear Tester. The study concluded that curing time and pavement location were insignificant factors and that increased residual application rate did not significantly improve the bond shear strength. The study also concluded that the milled sections exhibited significantly higher bond strengths and that the absence of tack coat did not affect the bond strength for the milled sections. The study also indicated that the UTEP Pull-Off test was generally ineffective for testing on milled sections. The overall average bond strength for the milled sections was 176 psi (range from 98 – 267 psi) and for the non-milled section was 60 psi (range from 18 – 117 psi).

Sholar, et al. (2002) investigated the HMA interlayer bond strength of constructed pavement sections using a direct shear apparatus at a strain rate of 2 in/min and a test temperature of 77 °F. Test sections were constructed using an RS-1 emulsified asphalt tack coat at application rates of 0, 0.02, 0.05 and 0.08 gal/yd^2. Water was also applied to the surface of the set tack coat on 2 sections (0.02 and 0.08 gal/yd^2) to simulate the effects of rain during paving. Six inch pavement cores were extracted at four time periods ranging from 1 to 99 days after paving. This study concluded that HMA interlayer bond strengths for the dry pavements increased with application rate and generally increased with time and that the presence of water reduced the bond strengths. A limited number of tests were also conducted on a milled HMA section, with the results indicating significantly higher bond strengths as compared to the non-milled sections and general insensitivity to application rate.

Mohammad, et al. (2005)investigated the HMA interlayer bond strength of laboratory prepared 19 mm NMAS specimens using the Superpave Shear Tester. The research factorial included 8 different tack coat materials (PG 64-22, PG 76-22M, SS-1, SS-1h, CRS-2P, CSS-1, CRS-2L, SS-1L), 2 test temperatures (77, 131 °F), five application rates (0, 0.02, 0.05, 0.1, 0.2 gal/yd^2) and 6 normal pressures (0, 20, 40, 60, 80, 100 psi). Based on paired analysis of the various test results, this study concluded that increased application rates generally decreased interface bond strength, especially at the higher test temperature, and that the CRS-2P and CRS-2L were identified as the beast tack coat types with an optimal residual application rate of 0.02 gal/yd^2.

Willis and Timm (2006) conducted a forensic investigation of a rich-bottom HMA test section which exhibited premature fatigue cracking attributed to interlayer slippage. Direct shear tests were conducted on 6-inch cores extracted from sections exhibiting distress and from sections without distress (control). Interlayer bond strengths between the SMA surface and HMA middle layer and between the HMA middle layer and the Rich-bottom layer were determined using a strain rate of 2 in/min. For analysis purposes, shear stresses at the outside edge of a loaded tire were computed at various depths using the WESLEA program assuming full and no bonding between layers. Figure 1 presents the results of this analysis.

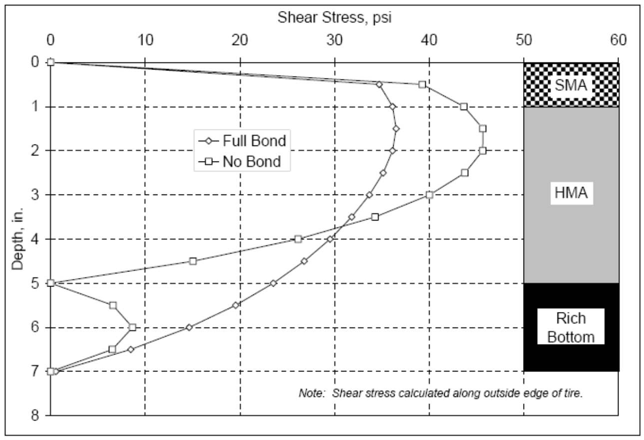

Figure 1: WESLEA Analysis Results (Willis & Timm, 2006)

Bond strengths measured between the HMA middle and rich-bottom layers were substantially higher than comparable measures between the SMA and HMA middle layers for all coring locations. However, the interlayer bond strengths measured for the distressed sections were comparable to those from the control section.

The research results presented above generally support the WisDOT Standard Specifications application rate of 0.025 gal/yd^2 and the restriction of applications before impending rains. The cited research also indicates that tack coat applications on milled surfaces, a common practice in Wisconsin and surrounding states, may be less critical than tack coat applications between HMA paving layers. While the cited research provides general recommendations on required bond strengths, preferred materials and application rates, more specificity is needed to quantify interlayer bond strengths resulting from allowable combinations of materials and applications within Wisconsin. This research is proposed to provide that specificity.

Benefits

The accomplishment of this study's objectives and implementation of its recommendations will have tangible economic and technical benefits for WisDOT. Findings will allow WisDOT to ensure that cost-effective tack coats are used in HMA pavement construction, and provide a basis to evaluate whether tack coats are properly applied in the field. This will result in increased confidence that HMA pavements will not show signs of slippage and shoving in the future.

Implementation

The successful completion of this study will provide WisDOT with data and understanding to ensure the cost-effective usage of tack coats in HMA pavement construction. Specifically, the research will be implemented in the form of changes to the WisDOT Standard Specifications, training for paving crews on the appropriate application of tack coats, or a combination of both.

Detailed Work Plan

This research will investigate the adhesion properties of tack coats, including but not limited to emulsions, modified emulsions and paving grade binders, by evaluating the following parameters:

- Tack coat application rate
- Tack coat and pavement application temperatures
- Tack coat curing period
- Type and condition of adhering surfaces
- Type of laboratory/field test equipment/protocol

A complete research factorial will be designed to encompass an appropriate testing range for the parameters listed above. Recommendations for a final testing factorial will be provided for review. Upon acceptance, the research factorial will be implemented through materials acquisition, specimen preparation, laboratory testing and data analysis.

The objectives of this study will be met through the work tasks summarized below.

Task 1 – Literature Review. The Marquette research team will continue the review of published research reports and papers focused on the measurement and analysis on interlayer bond strengths. Primary focus will be placed on bond strengths between constructed HMA layers and on test equipment/protocols that may be useful for both laboratory and field testing applications.

Task 2 – User Survey. The Marquette research team will survey WisDOT personnel and industry representatives to assess current practice for application of tack coats during construction. Telephone and electronic surveys will be conducted to establish typical tack coat material types, material suppliers, storage and application requirements, and surface preparation techniques. The results of these surveys will be used to better define the testing parameters and research factorial used during the laboratory testing program.

Task 3 – Develop Research Factorial. The Marquette research team will assess the current protocols for tack coat applications, as enumerated in Section 455 of the WisDOT Standard Specifications, and the results of the user survey to finalize the full research factorial appropriate for this study. Consideration will be given to the following parameters:

Tack Coat Type – Current WisDOT specifications allow for the use of MS-2, SS-1, SS-1h, CSS-1 and CSS-1h emulsified asphalts. Modified asphalt emulsions, such as the NTSS-1HM Trackless Tack material distributed by Blacklidge Emulsions, may also be considered for inclusion into this study. At least one paving grade asphalt, such as the common PG 58-28 or PG 64-22 binders, will be included. As indicated, at least 7 tack coat materials will be included in this study.

Tack Coat Application Rate **-** Current WisDOT specifications indicate an application rate of 0.025 gal/yd^2. To provide for meaningful comparisons, application rates of 0, 0.1, 0.025 and 0.04 gal/yd^2 are suggested to provide quantitative data on the effects of application rates. In addition to application rate, uniformity of coverage may play a critical role in the quality of the interlayer bond. For each selected application rate, 2 levels of uniformity representing both uniform and streaked coverage will be simulated.

Application Temperatures – The suppliers recommended storage and application temperatures for each tack coat material will be utilized in this study. The base temperature of the HMA supporting layer will be varied to simulate varying paving environments which may impact the activation of the tack coat and ultimately its adhering properties. Current WisDOT specifications require a minimum air temperature of 36 °F, which may be considered equal to the average base layer temperature. Additional base layer temperatures of 77 and 120 °F will be utilized to simulate a broad range of paving conditions. Specimens will be conditioned for a minimum of 24 hours at these temperatures prior to the application of tack coat materials and held at these temperatures during the curing period.

Curing Period – The current WisDOT specifications do not specifically address the required curing period for the tack coats. The results of the user surveys will be used to develop typical curing periods utilized during construction. It is anticipated that these curing periods will be established as a function of prevailing weather conditions, as simulated by the base layer application temperatures. For comparative purposes, an endpoint no-cure period will be used in additional to at least 2 curing periods which reflect mid-range and maximum values typically used for each paving environment.

Adhering Surfaces – Current WisDOT specifications indicate the tack coat may be applied only when the existing surface is dry and reasonably free of loose dirt, dust, or other foreign matter, a condition which must be achieved by sweeping immediately before tack coat application. For laboratory prepared specimens, simulation of these conditions will first require the base specimens to be exposed to an environment which allows for the accumulation of dirt & debris. These specimens will then be "cleaned" in a manner which simulates acceptable and unacceptable practice. For comparison, a control set of specimens will be utilized which simulate a debris-free environment prior to tack coat application. The mixture types for the base and overlying HMA layers also affects the quality of the bond provided by the tack coat. WisDOT standard specifications require 19.0 mm NMAS lower layers, 12.5 mm NMAS upper layers and 12.5 mm NMAS SMA surface layers. At a minimum, this results in 2 distinct HMA interface types which should be considered in this study.

Test Type – Based on the literature review conducted to date, the most promising test types include the direct shear and torque tests. Both tests may be conducted in the field, but each has some practical limitations. For comparative purposes, replicate tests will be conducted using both test configurations to determine which test may be most suitable for implementation.

Based on the seven parameters considered above, a full research factorial would include at least 6,048 research cells (7x4x2x3x3x3x2x2). Within each research cell, a minimum of 3 replicate specimens would be required for statistical purposes, resulting in a total of at least 18,144 specimens. The Marquette research team will analyze the fully developed research factorial to identify targeted research cells deemed most appropriate for inclusion into this study. This targeted factorial will be presented to WisDOT for review and approval.

Factorial Table A indicates proposed baseline testing considerations which include interface type, tack coat application rates, and test protocol. The interface types to be considered include an existing (non-milled) HMA surface overlaid with a standard 19 mm NMAS lower pavement layer and a 19 mm NMAS lower pavement layer surfaced with a 12.5 mm NMAS upper pavement layer. Application rates from 0 to 0.040 gal/yd^2 may be investigated, with curing periods selected based on typical mid-range values prevalent in Wisconsin for ambient temperatures indicated in Factorial Table B. (Note: No curing period necessary when application rate is 0 gal/yd^2). Testing will be conducted using both the torque bond and direct shear tests. For each combination of application rate, curing period, interface type and test protocol, three replicate specimens will be tested, with the average result and variability used for comparative purposes.

Factorial Table A (Note: Each cell has 3 replicate specimens)

Application Rate	Curing Period	Torque Bond Test		Direct Shear Test	
		Interface Type		Interface Type	
		Ex Surf /19mm	19 mm /12.5 mm	Ex Surf /19mm	19 mm /12.5 mm
0	None	I	II	I	II
0.010					
0.025					
0.040					
0.010	Mid-Range	III	IV	III	IV
0.025		III	IV	III	IV
0.040		III	IV	III	IV
0.010	Max-Range				
0.025					
0.040					

Factorial Table B indicates proposed testing conducted on Factorial A specimens conditioned at ambient temperatures of 36, 70 and 120 F. The upper portion of Factorial Table B represents testing with uniform tack coat applications, proposed using applications (0, 0.010, 0.025 and 0.040 gal/yd^2) of one emulsion and one PG binder. For convenience, the SS-1h emulsion and PG 58-22 binder are indicated, but these material types may change to reflect tack material types most commonly used in Wisconsin at the time of lab testing. Three levels of cleanliness are proposed for the existing surface based on the interface type. When simulating a pre-existing aged and dirty non-milled HMA surface which is to be overlaid with a 19 mm lower pavement layer, the surfaces of the initial gyratory specimens will be aged and allowed to accumulate dirt/debris. One subset of specimens will then be cleaned in a manner which represents adequate cleaning per WisDOT specification 455.3.2.3 (X cells) and a second subset will be minimally cleaned to represent conditions considered inadequate (X* cells). When simulating a relatively new 19 mm NMAS lower layer (i.e., the lower pavement layer initially placed during rehabilitation by overlay) which is to be overlaid with a 12.5 mm upper pavement layer, the initial gyratory specimen will be temperature conditioned and 1) tack immediately applied to simulate ideal conditions with no exposure to dirt/debris (X** cells) or 2) allowed to accumulate minor dirt/debris, such as that occurring during typical construction operations, and then cleaned in a manner considered adequate per WisDOT specification 455.3.2.3 (X cells).

Factorial Table B

Tack Type	Application Coverage	Temp = 36F			Temp = 70F			Temp = 120F		
		Debris Free	Cleaned OK	Poorly Cleaned	Debris Free	Cleaned OK	Poorly Cleaned	Debris Free	Cleaned OK	Poorly Cleaned
MS-2	Uniform									
SS-1										
SS-1h		X**	X	X*	X**	X	X*	X**	X	X*
CSS-1										
CSS-1h										
PG 58-22			X			X			X	
NTSS-1HM										
MS-2	Streaked									
SS-1										
SS-1h			Y			Y			Y	
CSS-1										
CSS-1h										
PG 58-22										
NTSS-1HM										

Each X cell has 48 specimens (All cells from Factorial Table A x 3 replicates)
Each X* cell has 24 specimens (All I and III cells from Factorial Table A x 3 replicates)
Each X** cell has 24 specimens (All II and IV cells from Factorial Table A x 3 replicates)
Each Y cell has 36 specimens (Excludes I and II Cells from Factorial Table A x 3 replicates)
Proposed Minimum Testing = 6 Uniform Coverage X Cells x 48 specimens = 288 specimens
3 Uniform Coverage X* Cells x 24 specimens = 72 specimens
3 Uniform Coverage X** Cells x 24 specimens = 72 specimens
3 Streaked Coverage Y Cells x 36 specimens = 108 specimens
Total Proposed Minimum Testing = 288 + 72 + 72 + 108 = 540 specimens

The lower portion of Factorial Table B proposes comparative testing to be conducted with the selected emulsion tack material applied in a streaked, rather than uniform, application on surfaces considered adequately cleaned per WisDOT specifications (Y cells). This is intended to investigate the potentially detrimental effects of improperly cleaned/calibrated spray nozzles on the tack distributor.

The proposed testing matrix includes 540 specimens (180 average test results) to provide sufficient data to quantify the effects of application rate, pavement temperature, curing period and surface preparation for a typical emulsion tack material applied to both aged HMA surfaces (90 data pairs) and newly placed HMA lower pavement layers (90 data pairs). In all cases, comparative tests will be conducted using both the torque bond and direct shear test protocol (90 data pairs). Additional data will be generated for adequately prepared surfaces to test the effects of tack material type (PG and emulsion tack materials, 36 data pairs) and uniformity of application coverage (36 data pairs for the emulsion tack material).

The results of the proposed testing will be useful in determining key test parameters, the appropriateness of existing specifications, and in identifying the most useful test protocol for laboratory and field use. Data trends will also help target untested factorial cells that will provide useful additional data. It is estimated that an additional 360 specimens may be fabricated and tested using the available project budget and time duration, which represents an additional 120 factorial cells that may be included in the overall study. Selection of additional test cells will be done to maximize the study results. For example, the initial factorial results may reveal consistent trends between test protocol (torque bond and direct shear tests) and interface type. If so, subsequent testing may focus on one test protocol/interface combination and complete a given column in Factorial Table A (6 additional cells, 18 specimens). Similarly, a 19mm /12.5mm interface column may be completely retested using an SMA mixture for the upper pavement layer (10 – 20 additional cells, 30 – 60 specimens). Also, using a targeted combination of application rate, curing period, interface and test protocol, any given column in Factorial Table B may be completed to provide insight on the affects of tack materials and application coverage (11 additional cells, 33 specimens). As indicated, the ability to utilize the initial proposed testing matrix to target untested factorial cells will provide optimal enhancement to the initial study results with limited additional testing requirements.

It should also be noted that the proposed initial testing factorial does not include any tests on milled HMA surfaces. This choice was made based on published research which indicates bond strength on this surface type is independent of tack material type and application rate, primarily due to the aggressive mechanical bond provided by the milled surface texture. For comparative purposes, selected cells completed during initial and/or subsequent testing may be targeted for replicate testing using field core samples obtained from milled HMA surfaces. Collection of these samples will be done by Marquette staff using Marquette's portable core drill at no additional project costs. Similarly, comparative in-place field tests can be completed by Marquette staff at no additional project costs using the torque bond tester.

Task 4 – Obtain Materials Samples. The Marquette research team will identify representative construction projects scheduled for completion early in the 2009 construction season. The team will travel to these sites during construction to obtain representative samples of HMA materials for use in specimen fabrication. Samples of tack coat materials will be obtained directly from material supplies. For the requirements of this study, it is envisioned that a 5 gallon bucket of each selected tack coat and material and 1 ton of each HMA mixture type will be sufficient.

Task 5 – Conduct Laboratory Testing. The Marquette research team will complete all laboratory testing within the Asphalt Materials Laboratory of Marquette University. All testing will be completed during the summer months when no active classes are scheduled. The bond strengths will be tested using both the direct shear torque bond testers. Proposed testing will be conducted on specimens fabricated in two steps using the portable gyratory compactor owned by Marquette University. Initially, HMA specimens will be compacted to a nominal height of 3 inches using HMA mixtures simulating pre-existing field conditions, i.e., the surface to which the tack coat will be applied (aged HMA or newer 19 mm lower pavement layer). After desired conditioning/cleaning of specimen surfaces and tack coat application, the gyratory compactor will again be used to compact an overlay composed of typical lower (19 mm) and upper (12.5 mm) pavement layer mixtures. Mixtures will be obtained from selected paving projects and compacted to minimum allowable thicknesses based on WisDOT specification 460.3.2.

Preliminary analysis of the torque bond test has been completed by the Marquette research team. Figures 2 – 4 illustrate example specimen fabrication, preparation and testing steps. This preliminary analysis indicates that this test protocol is easily adapted to both laboratory and field test applications.

Figure 2: Compacted Gyratory Specimen with 1.5" Overlay and 3" Base Layer

Figure 3: Prepared Specimen with 4-inch Core Cut Through Overlay

Figure 4: Specimen Set-up for Torque Test

Task 6 – Data Analysis. The results of all laboratory testing will be analyzed to develop significant relationships between testing parameters and interlayer bond strengths. Paired analyses, which consider the mean and standard deviation of each replicate test group, will be used as the primary comparative tool to assess the statistical significance of the test parameters.

The results of the proposed testing will be useful in determining key test parameters, the appropriateness of existing specifications, and in identifying the most useful test protocol for laboratory and field use. Data trends will also help target untested factorial cells that will provide useful additional data. It is estimated that an additional 360 specimens may be fabricated and tested using the available project budget and time duration, which represents an additional 120 factorial cells that may be included in the overall study. Selection of additional test cells will be done to maximize the study results. For example, the initial factorial results may reveal consistent trends between test protocol (torque bond and direct shear tests) and interface type. If so, subsequent testing may focus on one test protocol/interface combination and complete a given column in Factorial Table A (6 additional cells, 18 specimens). Similarly, a 19mm /12.5mm interface column may be completely retested using an SMA mixture for the upper pavement layer (10 – 20 additional cells, 30 – 60 specimens). Also, using a targeted combination of application rate, curing period, interface and test protocol, any given column in Factorial Table B may be completed to provide insight on the affects of tack materials and application coverage (11 additional cells, 33 specimens). As indicated, the ability to utilize the initial proposed testing matrix to target untested factorial cells will provide optimal enhancement to the initial study results with limited additional testing requirements.

It should also be noted that the proposed initial testing factorial does not include any tests on milled HMA surfaces. This choice was made based on published research which indicates bond strength on this surface type is independent of tack material type and application rate, primarily due to the aggressive mechanical bond provided by the milled surface texture. For comparative purposes, selected cells completed during initial and/or subsequent testing may be targeted for replicate testing using field core samples obtained from milled HMA surfaces. Collection of these samples will be done by Marquette staff using Marquette's portable core drill at no additional project costs. Similarly, comparative in-place field tests can be completed by Marquette staff at no additional project costs using the torque bond tester.

Task 7 – Reports. The following reports will be delivered to WisDOT by the Marquette research team:

- An Interim Report which provides a summary and analysis of the results of the literature review (Task 1) and user survey (Task 2).
- Quarterly reports on the progress of the research study.
- A final report documenting the work done for all tasks of this study.

A draft of the final report of the entire research effort will be submitted to WisDOT for review 3 months prior to the end date of the study. This draft will be revised in accordance with WisDOT review comments, and the final report will be submitted by the end date of the contract. The final report will be prepared in accordance with WisDOT publication guidelines.

Qualifications of the Research Team

Principal Investigator – James A. Crovetti, Ph.D., Associate Professor of Civil Engineering, Marquette University

Dr. James Crovetti, who will act as Principal Investigator, has extensive pavement design and analysis experience utilizing distress, roughness deflection and performance data. Prior to joining the faculty at Marquette University, Dr. Crovetti was a project manager and the lead FWD engineer at ERES International. Since joining the faculty at Marquette University, Dr. Crovetti has remained active in the area of pavement engineering and has served as principal investigator for numerous pavement research projects sponsored by WisDOT. Dr. Crovetti's current commitments at Marquette University, including teaching, administrative duties, and on-going research projects, will require an average of approximately 60% of his time during the projected project period. These commitments leave a reserve of over 1,200 hours of time for new projects, which more than adequately covers his proposed participation on this specific research project.

Mr. David Newman will provide research support primarily during the laboratory testing portion of this project. Mr. Newman serves as the laboratory manager for the Department of Civil and Environmental Engineering at Marquette University and is responsible for the upkeep of all laboratory testing equipment and the fabrication of specialized testing apparatus. Mr. Newman has no current commitments during the summer months when the majority of project activities are occurring.

Facilities Available

The Marquette University Transportation Research Center (MU-TRC) is affiliated with the Civil and Environmental Engineering program at Marquette University, which currently has over 300 undergraduate and 50 graduate students. The primary facilities are located in the Haggerty Engineering Hall and Olin Engineering Annex. All these facilities are backed with library facilities, computer facilities, and laboratory technicians capable of high-level research activities. Well-equipped mechanical and electronic shops manned by experienced personnel are also available.

The Civil and Environmental Engineering laboratory and research facilities at Marquette University include an asphalt materials laboratory, a concrete testing laboratory, environmental laboratories, hydraulics and fluids laboratories, a soil mechanics laboratory, a structural testing laboratory, computer aided design and computer graphics laboratories. All of the resources of Marquette University are made available during sponsored research activities, **at no additional cost** to the sponsoring agency.

Selected References and Publications Relevant to This Research

Mehta, Y., and Siraj, N., ***Evaluation of Interlayer Bonding in HMA Pavements***, Final Report, Wisconsin Highway Research Program, Study No. 0092-02-13, 2007

Mohammad, L., Wu, Z. and Raqib, M., ***Investigation of the Behavior of Asphalt Tack Coat Interface Layer***, Louisiana Transportation Research Center Report No. FHWA/L.A.04/394, 2005.

Sholar, G., Page, G., Musselman, J., Upshaw, P. and Moseley, H., ***Preliminary Investigation of a Test Method to Evaluate Bond Strength of Bituminous Tack Coats***, State Materials Office, State of Florida, Research Report FL/DOT/SMO/02-459, 2002.

Tashman, L., Nam, K. and Papagiannakis, T., ***Evaluation of the Influence of Tack Coat Construction Factors on the Bond Strength Between Pavement Layers***, Washington Center for Asphalt Technology Report # WCAT 06-002, 2006.

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West, R., ***Measuring the Bond Strength of Pavement Layers***, Southeastern Superpave Center News, 2006.

Willis, J. and Timm, D., ***Forensic Investigation of a Rich-Bottom Pavement***, National Center for Asphalt Technology Report 06-04, 2006.

WisDOT Standard Specifications, Section 455 - Asphaltic Materials, 2008.